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Project Summary

Review of Mathematical Modeling for Evaluating Soil Vapor Extraction Systems

David L. Jordan, James W. Mercer, Robert M. Cohen

Soil vapor extraction (SVE) is a commonly used remedial technology at sites contaminated with volatile organic compounds (VOCs) such as chlorinated solvents and hydrocarbon fuels. Modeling tools are available to help evaluate the feasibility, design, and performance of SVE systems. These models provide a means by which to quantify some of the important SVE operating processes. This report provides information on SVE model selection, data requirements, design, and application; describes the equations governing flow and transport processes; and highlights model limitations.

This Project Summary was developed by the EPA's National Risk Management Research Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

Soil vapor extraction (SVE), a demonstrated technology, enhances the removal of volatile chemicals from the subsurface through application of a vacuum at an extraction well to induce air flow through the subsurface toward the well. As of 1991, SVE comprised 13% of selected remedies at Superfund sites, and approximately 7% of leaking underground storage tanks. The flow of air enhances volatilization of compounds from the residual NAPL phase in soil pores and from the dissolved phase in soil pore water. The technology is particularly applicable to relatively volatile organic compounds (Henry's law constant > 10^{-3} atm-m^3/mole) residing in the vadose zone. The technology may also be applicable for removal of volatile light non-aqueous phase liquids (LNAPLs) floating on the water table or entrained in the capillary fringe, if the chemicals of concern have high vapor pressures (e.g., benzene). During SVE, contaminant removal is expected to be enhanced by decreasing soil moisture. As the percent of moisture decreases, air permeability increases. Increased organic carbon content will increase sorption to the soil matrix, decreasing SVE efficiency. Heterogeneous flow conditions also affect the efficiency of contaminant removal, with higher flow zones (preferential flow zones) cleaning up faster than low flow zones (less-permeable zones).

Air sparging, another SVE-related technology, generally involves the use of injection wells to inject gas (typically air) into the saturated zone below areas of contamination. Ideally, dissolved, separate-phase and sorbed contaminants will partition into the injected air, effectively creating an in-situ air-stripping system. This can take place within a single-well system, or the stripped contaminants can be transported in the gas phase to the vadose zone and collected by SVE wells. The advantage of such a system is that the treatment of groundwater and soil takes place in-situ, reducing the need for disposal of treated material. Although air sparging is a physical/chemical treatment process, the addition of air has the potential to promote biodegradation.

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The SVE process involves installation of vacuum extraction wells or trenches at strategic locations and depths. Air extraction can also be combined with air injection. The spacing of wells or trenches depends on soil properties such as permeability and porosity. Where the objective is to remove both air and water, dual vacuum extraction wells may be used. The injection wells for air sparging can be vertical or inclined, ranging to horizontal. Effective design and prediction of system performance can be difficult, depending on site conditions.

Tools are now available in the form of numerical models, that allow one to both screen for the potential feasibility of SVE, and design and estimate performance of the system. While modeling should not be considered an end in itself, it provides a means by which to quantify some of the important SVE operating processes. Modeling can provide estimated answers for numerous questions concerning the feasibility and usage of SVE. Screening models can be used in conjunction with site characterization data and best professional judgment to determine the potential feasibility of SVE at a contaminated site. Flow and transport models can then be used to enhance the system design process and estimate performance. This review includes a summary of critical information required in a SVE application. It also includes a model selection process, model usage guidelines, and case studies.

Methodology

At an "Integrated In Situ Treatment System Design Workshop" on August 10 and 11, 1993 in Edison, NJ, a need was identified to provide environmental managers with guidance on how models may be used to: (1) determine the viability of using SVE, (2) help design the SVE system, and (3) estimate system performance. The methodology used to provide this report was a literature review and analysis of the various codes that may be applied to SVE. The literature review, and basic information on SVE system design, are provided. This includes introductory material, model selection tips, and example applications. In addition, information is provided on flow and transport theory.

Applicable codes were divided into the categories of screening, air flow, and compositional flow and transport. For each of these categories, currently available models were compiled and reviewed. Several example applications utilizing a number of the codes are presented, along with three case studies.

Results

The result of this review is a technical document that highlights the following topics and guides the user through the processes of selecting and applying models to SVE sites. Technical information is provided in order to: (1) determine the types of problems that can be addressed by modeling; (2) highlight the methods that are commonly used to solve such problems; (3) determin the need for modeling at the site and, selecting a model for the site; (4) identify and illustrate the major processes governing air flow and contaminant transport in the subsurface; (5) present a discussion of model data needs; (6) review available commercial and public domain codes; and (7) present a suite of model applications and case studies.

Conclusions

Modeling can provide estimated answers for numerous questions concerning the feasibility and usage of SVE. Screening models can be used in conjunction with site characterization data and best professional judgment to determine if SVE at a contaminated site is feasible. Flow and transport models can be used to enhance the system design process and estimate performance. In some cases, no complex model is necessary, and decisions can be made based on simple analytical solutions and/or best professional judgment. Geographical information systems (GIS) can provide valuable assistance in organizing and presenting site data graphically in order to enhance the remedial alternative selection process.

A total of six computer programs were evaluated, including the screening, air flow, and compositional flow and transport codes. For screening, these models include the HyperVentilate and VENTING codes, as well as other analytical solutions. Air flow models available at this time include AIRFLOW, CSUGAS, and AIR3D. For compositional flow and transport, the VENT2D/VENT3D model is available and capable of simulating contaminant transport and removal via SVE.

The selection and application of any model will ultimately lie with the model user. This document attempts to provide the potential model user through a decision-making process that is intended to help decide how and when to select a model, to make users aware of the processes governing flow and transport in the vadose zone, and highlight the limitations of model results.

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David L. Jordan, James W. Mercer, and Robert M. Cohen are with GeoTrans, Inc., Sterling, VA 20166
Chi-Yuan Fan *is the EPA Project Officer (see below).*
The complete report, entitled "Review of Mathematical Modeling for Evaluating SVE Systems," (Order No. PB95-243051; Cost: $36.50, subject to change) will be available only from:
National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650
The EPA Project Officer can be contacted at:
National Risk Management Research Laboratory
U.S. Environmental Protection Agency
Cincinnati, OH 45268

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